*Photogrammetric Mapping of Sand Beds in a Hydraulic Test Flume**

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ABSTRACT: *Progress in any science involves not only the development of new basic knowledge or new instruments and techniques; it embraces also a widening of the scope of well-established principles. I would like to discuss a specific bit of progress in the latter category.*

This paper describes no new instruments or methods. It deals with the application of a familiar technique to the solution of a particular problem, albeit a somewhat out-of-the-ordinary one. The familiar technique is aerial mapping, although no airplanes are involved in this application. The particular problem is to show accurately the configuration of sand dunes on the bed of an experimental river channel by means of a contour map.

EVOLUTION OF THE PROBLEM

THE U. S. Geological Survey is deeply concerned with the gathering of a wide range of information on hydrological phenomena. Linked to the major problem of water shortages and soil erosion, which threaten the economy and well-being of some parts of our nation, is the related problem of river flow. Several fluvial studies now in progress are concerned with the dynamics of sediment transport, the shapes of stable equilibrium channels, and the parameters controlling roughness of alluvial channels in which the configuration of the bed varies with the conditions of flow. In studying these problems, the Geological Survey is conducting experiments in the hydraulics laboratories at the University of Maryland and at Colorado State University. Figure 1 shows a typical initial condition at the start of one of these experiments in the flume at the University of Maryland; the channel is formed of selected uniform sand.

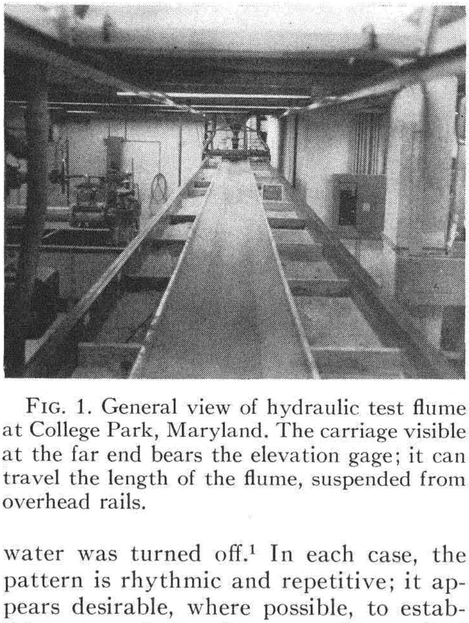

FIG. 1. General view of hydraulic test flume at College Park, Maryland. The carriage visible at the far end bears the elevation gage; it can travel the length of the flume, suspended from overhead rails.

Sand dune configurations resulting from such experiments vary in complexity from relatively simple patterns, as shown in Figure 2, to quite complicated patterns, as shown in Figure 3, photographed while the water was flowing, and Figure 4 showing the final pattern of the same run after the water was turned off.[1] In each case, the pattern is rhythmic and repetitive; it appears desirable, where possible, to establish a correlation between the cyclical characteristics of the dunes and the hydraulic parameters.

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[1] Figures 3 and 4 refer to a study reported in *U. S. Geological Survey Professional Paper 282-B* entitled "River Channel Patterns: Braided, Meandering, and Straight" by L. B. Leopold and M. G. Wolman.

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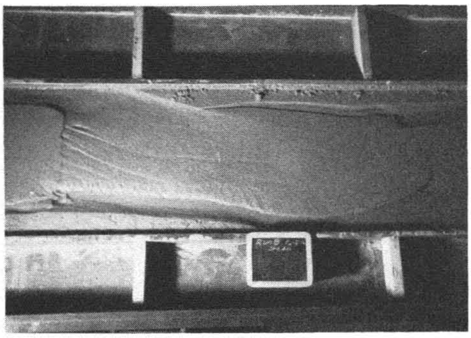

FIG. 2. Sand bed pattern with relatively smooth configuration.

Wave lengths and amplitudes at selected locations in these dune cycles are measurable at the Maryland lab with the aid of an elevation gage attached to a carriage riding on rails above the flume; but in general the observations provide only an elementary two-dimensional picture. There is one way, however, to record the total configuration permanently—by preparing an accurate contour map. Contour maps also provide a means of determining the amount of material deposited on or removed from a given area of the stream bed within a given period of a specified flow. A contour map showing the configuration at the beginning of the period can be used to determine the initial volume of material above a given datum; a second map, showing the configuration at the end of the period can be used to determine the final volume above the same datum. The difference between the two volumes represents the amount of material deposited or removed during the period.

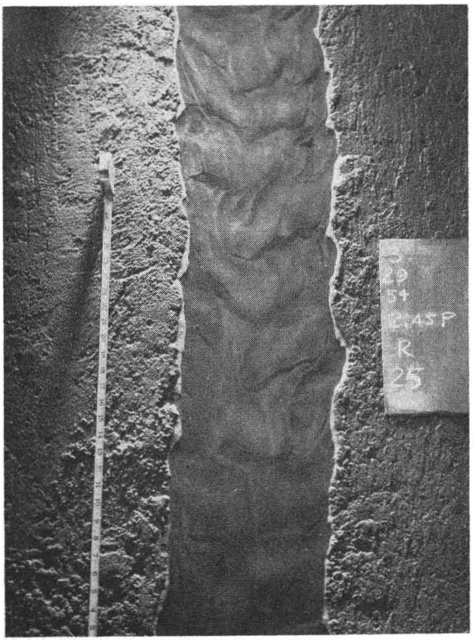

FIG. 3. Water flowing in sand channel during test run giving rough configuration.

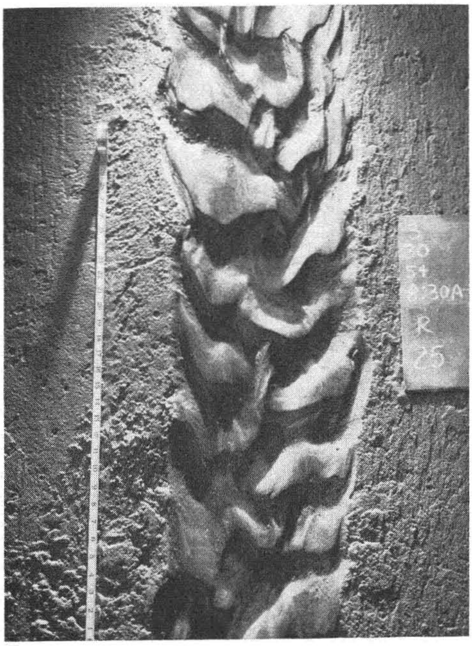

FIG. 4. Residual sand pattern at conclusion of flow shown in Figure 3.

Recognizing the value of permanently recording the total pattern, Geological Survey engineers tackled the problem of devising a practical method of mapping the sand dunes. To people familiar with modern topographic mapping procedures, it is plain that this problem can be solved by the application of standard photogrammetric techniques, with only incidental variations. Accordingly, an experimental project for mapping the sand beds in the College Park test flume was activated.

REQUIREMENTS

In order to plan the operations for this mapping project, it was first necessary to define the requirements. A study of the planned uses of sand-dune maps led to the adoption of the following specifications:

Area to be Mapped. The mapped area shall have a width approximately equal to the width of the flume (4 feet) and a length (established at 5 feet) sufficient to cover several cycles of the dune pattern.

Map Scale. The final map shall have a scale of 1:2 (half-size). (This scale was selected to give the largest scale possible without requiring an excessive size of the map sheet. Thus, for a coverage of 4 feet by 5 feet, the sheet size would be 24 inches by 30 inches, plus margins.)

Contour Interval. The contour interval shall be 0.01 foot. (This interval is suitable for adequately representing the sand dunes which have a total height variation, in the College Park flume, of about 0.25 foot.)

Accuracy. No horizontal-accuracy requirement is specified as no planimetry is involved. The standard requirement for vertical accuracy is to be assumed in planning, although it is not critical that this requirement be fully met. (For planning purposes, it was thus assumed that 90 per cent of elevations obtained from the map shall be correct within $\frac{1}{2}$ contour interval.)

OPERATIONAL PLAN

After the requirements had been established, a detailed plan of operation was drawn up on the basis of the technical factors pertaining to the project. The general plan adopted was to proceed as in a conventional aerial mapping project, with the following broad phases:

1. Establish ground control.
2. Photograph the area with a suitable camera at an appropriate height and with exposures properly spaced.
3. Make diapositives and orient them in a suitable stereo-plotting instrument.
4. Compile map detail.
5. Make reproductions of the map.

Ground Control. The ground control plan was quite simple. A tack would be stuck in the sand at each of the four corners of the neat model, with the head of the tack flush with the surface. Distances between the tacks would be accurately measured for horizontal control. Elevations on the tack heads would be obtained by means of the elevation gage attached to the carriage above the flume.

Photography. Because of the requirement of standard vertical accuracy, it was clear that a precise photogrammetric camera of known characteristics would be required. It was also clear that a conventional aerial mapping camera could not be used without some internal modification, for each of these cameras is set for an object distance of infinity—meaning that the principal distance setting in the camera is essentially equal to the focal length. Thus, the need was for a mapping camera which could be altered by changing its principal distance in correlation with the finite object distance represented by the height of the camera lens above the sand dunes. In other words, we had to satisfy the basic lens formula:

$$\frac{1}{O}+\frac{1}{I}=\frac{1}{F}$$

where

O = object distance,

I = image distance,

and

F = focal length of lens.

Fortunately, the Geological Survey had available a Zeiss P-10 camera with mount and a spare distortion-free Planigon lens having a focal length of 101.44 millimeters which could be used to replace the 99.2 millimeter Topogon lens in the P-10. Also available were spacers which could be used to change the principal distance.

Before a new value could be determined for the principal distance, it was necessary to consider the geometry of the photographic exposures, as follows:

1. A base-height ratio of $\frac{2}{3}$ for vertical photography was assumed.
2. An airbase of 4 feet was assumed so that the entire flume width could be covered in one model.
3. For a base of 4 feet and a base-height ratio of $\frac{2}{3}$, the height was determined to be 6 feet. This was a tentative, approximate value.

For an object distance of 6 feet, the tentative principal distance I (in millimeters) was derived from the formula as follows:

$$\frac{1}{6\times 304.8}+\frac{1}{I}=\frac{1}{101.44}$$

from which $I = 107.4$ millimeters

Examination of available lens spacers indicated that the principal distance could be changed to 108.1 millimeters without requiring additional shop work. On the basis of this value, a modified object distance was determined from the same formula to be 1,646.5 millimeters, or 64.8 inches, for optimum focus, giving a photographic scale of 108.1/1,646.5 or 1:15.2. For

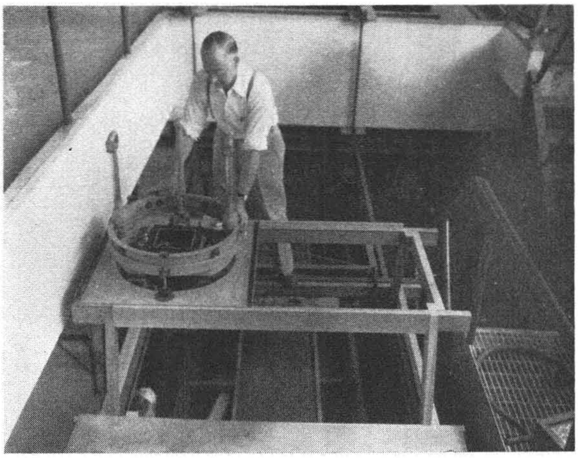

FIG. 5. Zeiss camera-and-mount assembly installed on specially built frame. Camera can be moved to second exposure station by sliding to right in the ways at top of frame. Magazine has been demounted from camera cone.

FIG. 6. Stereogram of sand configuration in first experimental project.

practical purposes, the nominal height of photography was considered to be 65 inches.

As the channels in the sand are always somewhat narrower than the 48-inch full width of the flume, the airbase finally selected was 40 inches, giving a base-height ratio of 40/65 or 0.615, which is within the usual range of values for wide-angle cameras.

Another important requirement in planning the photography was to provide a simple and inexpensive frame to accommodate the camera-and-mount assembly and to permit convenient sliding of the assembly from one exposure station to the other. This frame (see Figure 5) was designed by R. E. Ask, Chief of our Optical Unit, who also worked out the problem of camera calibration and modification described above and was responsible for the actual flume photography.

Stereoplotting Instrument. The selection of the stereoplotting instrument for compiling the map was limited by the change in the principal distance of the camera. To obtain proper diapositives for the Kelsh plotter, the printer ratio would have to be 108/153, for the ER-55, 108/55, or for the Multiplex, 108/30. As no printers affording such ratios are available, none of the instruments mentioned could be readily used. The project is made to order, however, for the Wild A-8, in which the principal distance can be changed to 108.1 by a simple adjustment. For compatibility with the distortion-free photography, the A-8 plotter is used without distortion-correction plates.

Compilation. Compilation at a scale of 1:2 from photography at a scale of 1:15 is conveniently arranged on the A-8 instrument by appropriate setting of the model scale and the coordinatograph. For a contour interval of 0.01 foot and an exposure height of 65 inches (5.4 feet), the C-factor is 540, well within the capability of the A-8. The manuscript sheet was specified to be a scribing base.

Reproduction. Compilation on a scribing base permits any number of copies to be made directly from the original by contact printing.

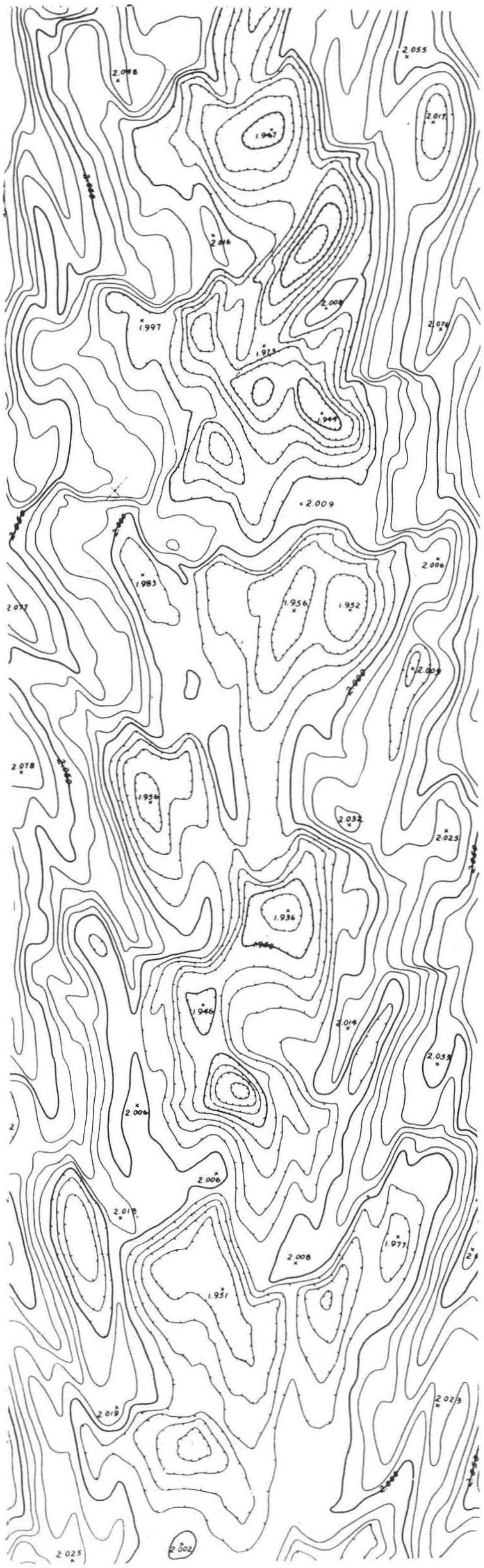

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FIG. 7. Portion of contour map produced in first experimental project.

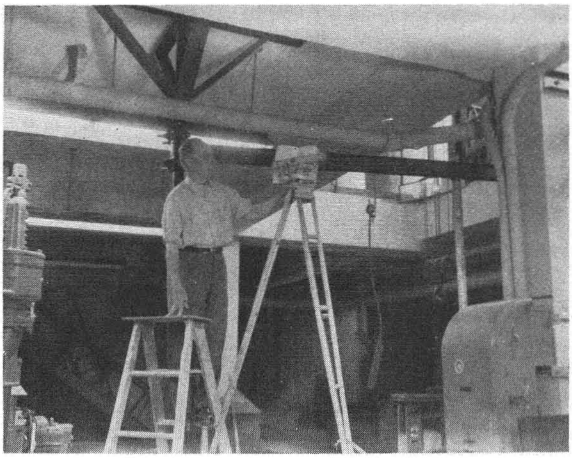

FIG. 8. High setup of precise level for reading elevations on sand bed check points.

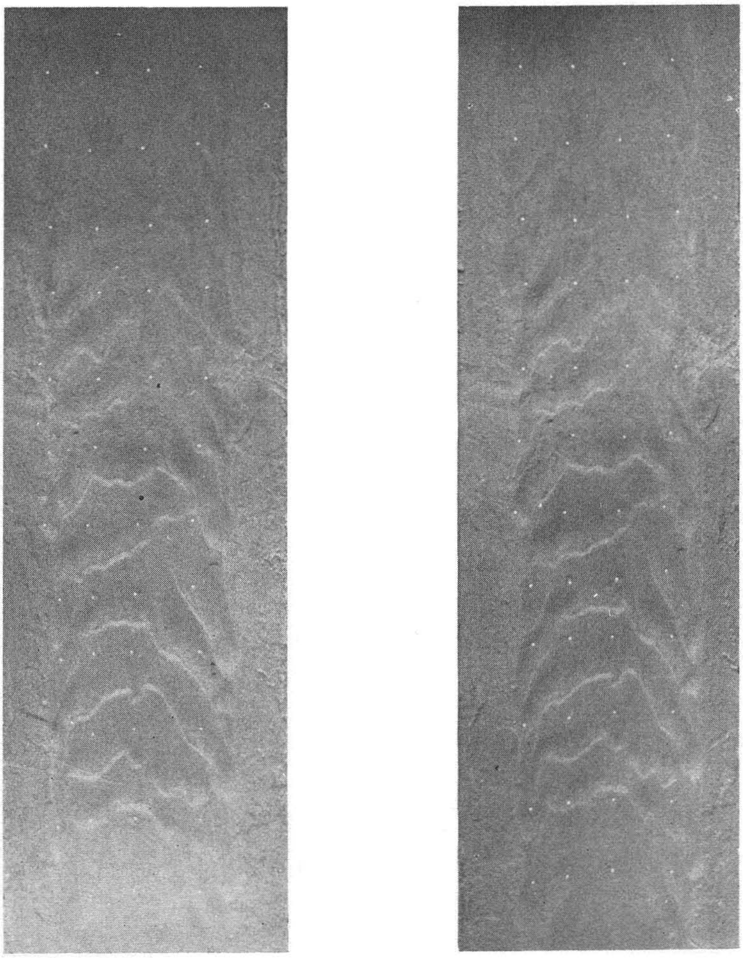

FIG. 9. Stereogram of sand configuration in second experimental project. White spots are heads of tacks, used as vertical-accuracy check points.

FIRST EXPERIMENTAL PROJECT

The first experimental mapping project was carried out entirely according to plan. Although the lighting arrangements left something to be desired and the only available film was somewhat over-age, the photographs (Figure 6) showed remarkable stereoscopic detail when set up in the A-8. The map (Figure 7) was produced without any particular difficulty.

The cyclical recurrence of ridges and depressions in the sand-dune pattern is plainly evident on this map. The Geological Survey, recognizing the value of such data, is seeking to develop a means of establishing mathematical correlations between the factors involved. Meanwhile, it was realized that we had not proved the accuracy of this mapping system, although the men who worked on the compilation, J. L. Crabtree, W. D. Kelley, and H. F. Ewing assured us that there was every reason to assume that very high accuracy had been achieved. As a corollary question, a need was recognized to prove that the elevation gage used to measure control elevations maintains reliable readings as the carriage which bears it is moved along the overhead rails. In order to determine both map accuracy and the accuracy of the depth gage, a second project was therefore set up.

SECOND EXPERIMENTAL PROJECT

The second project was carried out in a manner similar to the first, with the important addition that it included provision for complete accuracy checking "in the field." The check points consisted of 48 numbered tacks, carefully set in the sand in a regular (but not measured) pattern, with their heads flush with the sand surface. Prior to taking the photography, two height readings were made on each tack. One of these readings was a direct reading of the elevation gage, using the index mark and vernier mounted on the carriage; this reading would be affected by any deviation of the rails from flatness, lack of roundness of the carriage wheels, or other source of error. The second reading was a precise level reading (Figure 8) on a second scale mounted on the elevation gage, made by one of the control men, G. B. Grunwell. The level tripod was set on a steel table in

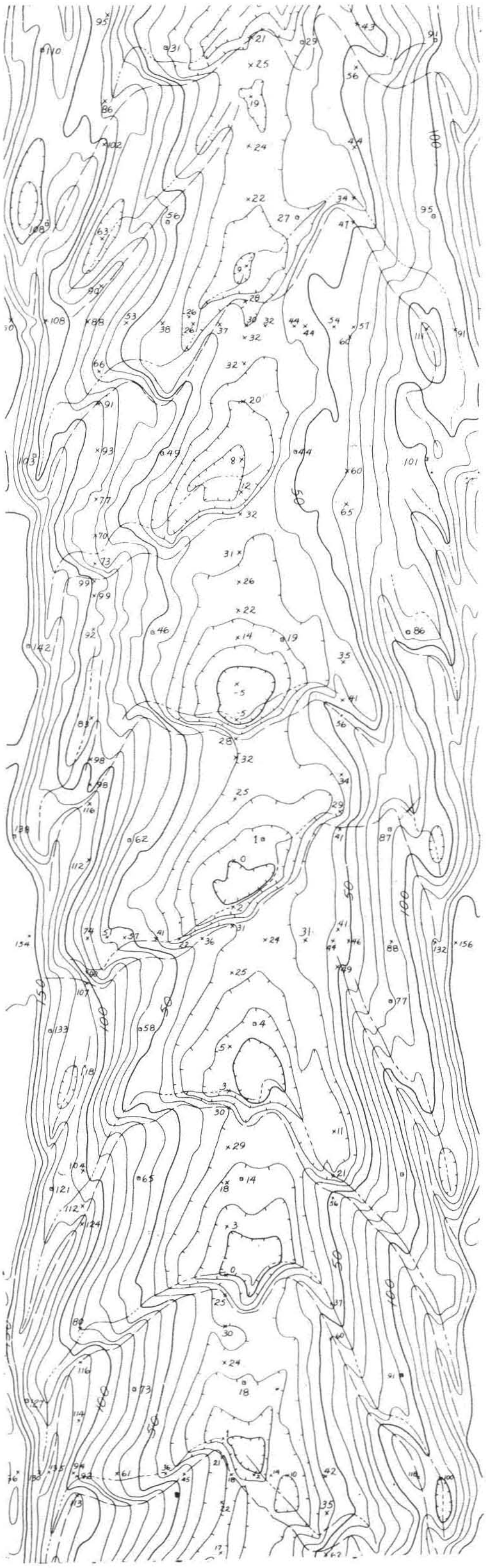

FIG. 10. Portion of contour map produced in second experimental project

order to obtain the required height of instrument, about 8 feet above the floor of the lab.

These readings were independent of the errors that would effect the carriage vernier reading, and therefore afforded a means of checking. A subsequent comparison of the two sets of readings showed the difference to be negligible for practical purposes, permitting the conclusion that direct elevation-gage readings would be satisfactory on future projects.

The check points showed up plainly as white spots in the aerial photographs (Figure 9). The "field-determined" elevations were withheld from the stereoplotting personnel who used only four corner elevations in setting up the A-8 model. In connection with the map compilation (Figure 10) the position of each check point was carefully marked and an elevation was read on it. In addition to drawing the contours, the operators read and marked spot elevations along certain lines where profiles were desired. Also, "ridge" lines and "drain" lines were delineated.

As the object of checking the map was to determine the accuracy of the contours, rather than of spot heights, a map elevation was determined for each check point by interpolation between contours. These interpolated elevations were compared with the corresponding field-determined elevations to obtain the elevation error at each point. The results of this accuracy check, based on 48 check points and a contour interval of 0.01 foot, are as follows:

Elevations correct within 1 contour interval $=100\%$
Elevations correct within $\frac{1}{2}$ contour interval $=94\%$
Elevations correct within $\frac{1}{4}$ contour interval $=67\%$
Mean square error $=0.0028$ foot
(Allowable, for standard accuracy $=0.003$ foot)
Maximum error $=0.007$ foot

CONCLUSION

The results obtained indicate that the mapping system described can produce 0.01-foot contour maps that meet high standards of accuracy. They also indicate that for the purpose to which maps of this type will be put, the question of accuracy need never be a limiting factor in interpreting map data. A fertile field for further research would be in the direction of using photographs made while the flow is in progress.

This application is one more example of the almost limitless field of engineering and scientific uses to which photogrammetry can be applied. We need to keep pressing for new and better techniques and instruments, of course; and yet it is comforting to know thst there are many fascinating jobs that we can do right now by intelligent application of tried-and-true principles that have long been known.

AIR PHOTO INTERPRETATION OF SOILS AND GEOLOGY

How air photo interpretation provides essential soils and geologic data for engineering projects is reported in a new 4-page folder published by Aero Service Corporation, Philadelphia.

Soils can be mapped for their engineering properties, according to Aero engineers and geologists. They say soil texture, plasticity, internal and external drainage can be determined by experienced photo-interpreters.

Area geology can also be mapped for engineering purposes from stereoscopic study of overlapping air photos. Estimates of difficulty of excavation, susceptibility to slides, depth of bedded rock and rock types can be made.

The folder also discusses the use of air photo studies to locate construction materials, determine trouble areas, aid route location, and to investigate excavation and foundation problems. Several examples of air photo interpretation are shown.

Copies of the folder, "Air Photo Interpretation of Soils and Geology for Engineering Projects" are available on request. Send to Company's Philadelphia office.